Closure Phase Interferometry: Lambda Andromedae

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Thesis Project

- Interferometric modelling of active giants
- Study stellar spot characteristics
- Compare results to measure of B field
- Began with pilot study of Lam And
Committee and Collaborators

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Special Thanks
Ming, Chris, PJ, CHARA team
Motivations

• Better understanding of spot characteristics
  – Tracer of B fields
  – Stellar rotation

• Current spot “imaging” methods problematic
  – Too little information (light curve inversion)
  – High dependance on a priori information (doppler tomography)
Target List

• Instrumentation criteria
  – Dec > 5°
  – H mag < 4th
  – Θ = 1 – 4 mas

• Target criterion
  – Single [truly or SB1] giants
  – Δ V mag > 0.1

• Initially RS CVns
Auxillery Observations

- Hard Labor Creek Observatory (GSU) or Fairborn Observatory (TSU)
- Simultaneous or contemporaneous
- Photometry UBV(RI)$_c$
  - Check to expected flux loss
  - Measure of effective temperature
- Spectroscopy $R \sim 30,000$
  - Measure of eff. temp., log g, H$\alpha$ line strength
  - Could be used to create Doppler map
  - Could be used to measure B field – Zeeman splitting
Pilot Study: Lam And

- CHARA/MIRC beam combiner
  - Prefer phase information over spot contrast
- First epoch
  - November 17, 2007
- Second epoch
  - August 18th – 21st, 2008
- Third epoch
  - September 20th, 2008
Visibility Curve

1\textsuperscript{st} Lobe: Star Size
2\textsuperscript{nd} Lobe: Limb-darkening, spot size
3\textsuperscript{rd} Lobe: Spot size, small-scale structure
Visibility Comparison
Closure Phase

Measured Source “Antenna”

\[
\begin{align*}
\Phi_{12} &= \phi_{12} + \varepsilon_1 - \varepsilon_2 \\
\Phi_{23} &= \phi_{23} + \varepsilon_2 - \varepsilon_3 \\
\Phi_{31} &= \phi_{31} + \varepsilon_3 - \varepsilon_1
\end{align*}
\]

Combine \(\Rightarrow\)

\[
\Phi_{12} + \Phi_{23} + \Phi_{31} = \phi_{12} + \phi_{23} + \phi_{31}
\]

- Source terms are baseline-dependent.
- Error terms are antenna-dependent.
“Lambdy Andy”


\[ \Pi = 38.74 \pm 0.68 \text{ mas} \]
\[ \text{vsini} = 6.5 \text{ km/s} \]
\[ P_{\text{phot}} = 54.33 \text{ days} \]
\[ P_{\text{orb}} = 20.5212 \text{ days} \]
\[ H \text{ mag} = 1.501 \]
\[ \Delta V \text{ mag} = 0.22 \]


SB1, white dwarf companion
G8 III

Monnier (unpub.)

\[ M = 0.65 M_{\text{sun}} \]
\[ R = 7.5 R_{\text{sun}} \]

11 yr stellar activity cycle (Hall 1991)
Spot Model

• 8+ parameters
  – Star size, limb-darkening coefficient, ellipticity, spot size, spot position [x,y], flux ratio, temp. profile coefficient
  – Model capable of any number of spots

• Minimization on visibility or closure phase (Filho 2008)

\[
\chi^2_{\text{V}}(z) = \sum \frac{1}{\sigma_{V_i}^2} \left( V_{\text{data}}^i - V_{\text{model}}^i \right)^2
\]

\[
\chi^2_{\text{T}}(z) = \sum \frac{1}{\sigma_T^2} \left| e^{i\phi_{\text{data}}} - e^{i\phi_{\text{model}}} \right|^2
\]

• Grey limb-darkening relation: \(1-\epsilon + \epsilon \cos \Theta\)
Limb-darkening Disk

Size: 2.750 mas
Epsil: 0.462
$\chi^2_V$: 9.818
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Elongated Limb-darkening Disk

Size: 2.819 mas
Epsil: 0.467
Ellip 0.0469
$\chi^2_V$: 8.109
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Elongated Limb-darkening Disk w/ Spot

Star Size: 2.819 mas  Spot Size: 1.13 mas
Epsil: 0.467  80 pixels
Ellip 0.0469  x: 60
$\chi^2_V$: 10.847  y: 60
$\chi^2_C$: 0.016
Elongated Limb-darkening Disk w/ Spot

Star Size: 2.819 mas  Spot Size: 1.13 mas
Epsil: 0.467  80 pixels
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The News So Far...

- Closure phase show asymmetries
- Simple models insufficient
- Strong signs towards spotted surface
Future Plans

• Improved method of minization
• Addition of elongation position angle
• More complicated spot structures
• Apply to multiple epochs of data
• Magic happens → Graduate